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Research on Soil Erosion Intensity and Spatial Distribution Characteristics in Zhaoyang District of Zhaotong City Based on RS and GIS

Maohua Pan[1], Ruei-Yuan Wang[2,*], Bing-Yuh Lu[3]

[1,2]School of Sciences, Guangdong University of Petrochem Technology(GDUPT), China
[3]Faculty of Automation, Guangdong University of Petrochemical Technology, China
Corresponding author

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Abstract— *This article takes Zhaoyang District, Zhaotong City, Yunnan Province, as the study area. By obtaining basic data such as rainfall, soil texture data, digital elevation, land use, and remote sensing images, the RUSLE model is used to estimate the soil erosion modulus in Zhaoyang. Based on this, the soil erosion classification and soil erosion of different land use types in the study area are analyzed. The results have shown that the soil erosion intensity in Zhaoyang, shows a pattern of increasing from southeast to northwest. Most of the land is subject to slight erosion, followed by mild and moderate erosion. The strongly eroded soil is concentrated in the northwest and is greatly affected by altitude and slope factors. The proportion of soil micro erosion is 64.4%, the proportion of mild erosion area is 17.58%, the proportion of moderate erosion area is 11.99%, and the proportion of strong erosion, extremely strong erosion, and severe erosion area are 3.74%, 1.55%, and 0.74%, respectively. The erosion amount of land use types such as construction land and water bodies is very small, and overall it is at a micro erosion level. Shrubs, forests, and grasslands are the main sources of regional erosion, and the soil erosion intensity of cultivated land is high.*

Keywords— ***Revised Universal Soil Loss Equation (RUSLE), Land Use-Cover Change (LUCC), Soil Erosion, Remote Sensing (RS), Geographic Information System (GIS)***

I. INTRODUCTION

Soil erosion is the most common form of destruction of soil resources and refers to the processes of destruction, denudation, transportation, and deposition of soil and its parent materials under the action of hydraulic, wind, freeze-thaw, gravity, and other external labor. Soil erosion will not only destroy land resources and reduce land productivity but also aggravate the occurrence of other disasters such as floods, droughts, and debris flow, threatening the production and development of human society. It will also affect the comprehensive utilization and development of the soil. Therefore, soil erosion and its nutrient loss have become the focus of researchers.

With the continuous development and maturity of RS and GIS technology, researchers at home and abroad have made a lot of achievements in the monitoring and analysis of regional soil erosion, including the universal soil loss equation (USLE) [1] [2] [3], the general soil loss equation water erosion prediction watershed model (Water Erosion Prediction Project, WEPP) [4] [5] [6], the Chinese soil loss equation (CSLE) [7], the Limburg Soil Erosion Model (LISEM) established in the Loess region of the Netherlands [8], and the European soil erosion model (EUROSEM) proposed by Morgan et al. [9]. Meanwhile, the new soil erosion equation of A=CSLKP proposed by Smith and Whitt [10], the soil erosion model (SWAT) for predicting the long-term impact of land management practices on watershed runoff and sediment yield [11], and the revised universal soil loss equation (RUSLE) [12] [13] [14] include many soil erosion calculation models. Among them, the RUSLE model is the most widely used. The RUSLE model has the characteristics of a simple structure, few parameters, and an accurate prediction of average soil erosion. From the spatial scale of the model, the study of soil erosion based on the RUSLE model includes not only slope scales and watershed scales but also regional scales, so it is suitable for the study of community scales in Zhaoyang District of Zhaotong City.

As an important area of national key management for soil and water loss in the lower reaches of the Jinsha River, Zhaoyang is faced with serious problems of soil and water loss and needs key control and management. As one of the main battlefields of ecological security barrier construction in the upper reaches of the Yangtze River, Zhaoyang, which is located in the lower reaches of the Jinsha River, is not only an important ecological security barrier in the upper reaches of the Yangtze River but also the most frontier pass for Yunnan to build ecological security barriers in the upper reaches of the Yangtze River. Serious soil and water loss not only causes the deterioration of the local ecological environment, people's poverty, and economic backwardness, but also poses a great threat to the safety of downstream flood control, reduces the flood diversion and storage capacity of rivers, and increases flood and waterlogging disasters. It is not conducive to navigation, which shows the urgency and seriousness of the problem of soil and water loss in the Zhaoyang area.

This article takes Zhaoyang District, Zhaotong City, as the study area and comprehensively uses ArcGIS and ENVI software and the RUSLE model to analyze the changes in land use, vegetation distribution, and soil erosion status in the study area. In order to protect and reasonably develop land resources, effectively prevent and control soil erosion, improve the ecological environment, and promote sustainable economic and social development. Meanwhile, to provide decision-making support for the sustainable development of the region while also strengthening the ecological security barrier in the Jinsha River Basin of Zhaoyang, Yunnan is promoting the construction of ecological security and ecological barriers, which is of great strategic significance for achieving the overall goal of ecological civilization construction in Yunnan and maintaining the overall ecological security of the country.

II. STYDY AREA AND DATA SOURCES

2.1 Study Area

Zhaoyang District is the administrative center of Zhaotong City, the political, economic, cultural, and information center, and the interprovincial central city of Yunnan, Guizhou, and Sichuan provinces, with geographical coordinates of 27 °7'~ 27 °39 °N, 103 °8 °103 °56 E. Located in the northeast of Yunnan Province (Figure 1), the topography is high in the west and low in the east, which is the northeast end of the concave part of central Yunnan. There is a relatively complete plateau landform in the Wumeng Mountains and Hengduan Mountains. The highest point is Dushi Baobao, Dashanbao Township, with an elevation of 3,364 m, and the lowest is Maopo on the bank of the Jinsha River at an altitude of 494 m, with a large elevation difference and an obvious three-dimensional climate.

It is the monsoon vertical climate of the plateau; the precipitation is concentrated in May–August, mostly in the form of torrential rain, forming a strong surface runoff and serious erosion to the soil. The geological conditions in the area are complex, and the soil types are complex and diverse due to different climates, altitudes, geomorphologies, and topographies. There are 7 types, 9 subclasses, 20 genera, and 80 soil species.

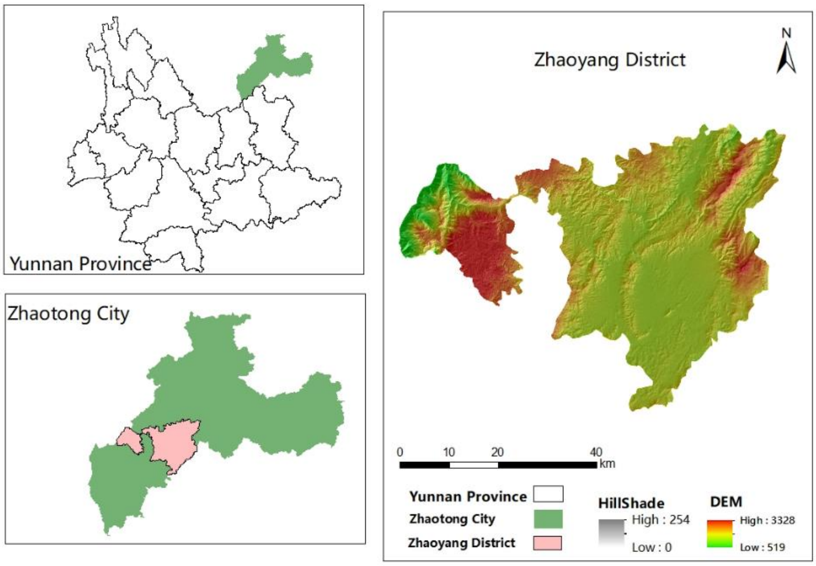

Fig.1 Topographic Map of Zhaoyang

2.2 Data Collection

This study mainly uses the following data (Table 1):

Landset-8 OLI_TIRS image data downloaded from geospatial data cloud (https://www.gscloud.cn/), temporal resolution 16 days, spatial resolution 30m × 30m, we download 2019 satellite image map, NDVI map made by ENVI5.3, and land use type map of Zhaoyang District, which are used to calculate vegetation cover factor C value and soil and water conservation P value.

The precipitation data comes from the Resource and Environmental Science and Data Center (RESDC) of the Chinese Academy of Sciences (https://www.resdc.cn/), which is used to calculate the rainfall erosivity factor R.

The topographic data comes from the geospatial data cloud (https://www.gscloud.cn/). a spatial resolution of 30m × 30m, which is used to extract slope length and calculate the LS value of the slope length factor.

The soil texture type data comes from the Harmonized World Soil Database (HWSD). The soil texture type map of Zhaoyang District, Zhaotong City, is extracted from the HWSD data, and four fields of SAN (sand), SIL (silt), CLA (clay), and C (organic carbon) are added to the layer attributes. Using the field calculator and the soil erodibility K value calculation formula, the soil erodibility K value is calculated.

Table 1 Collection Data Source

Data requirement	Data sources	Application
Landset-8 OLI_TIRS image data	Geospatial Data Cloud （https://www.gscloud.cn/home#page1/1）	Calculate C and P factors
Precipitation data	Resource and Environmental Science and data Center of the Chinese Academy of Sciences (https://www.resdc.cn/)	Generate R factor layer
30m DEM	Geospatial Data Cloud （https://www.gscloud.cn/home#page1/1）	Calculate LS factor
Soil texture	National Qinghai Tibet Plateau Scientific Data Center（https://data.tpdc.ac.cn/home）	Generate K-factor layer

III. METHODOLOGY

3.1 Method

This study is based on 30m DEM, 2019 precipitation data, HWSD, and 2019 Landset-8 OLI_TIRS image data in Zhaoyang. The main analysis steps (Figure 2) are as follows:

1. Using the soil texture type data, the soil texture type map of Zhaoyang is extracted, and four fields are added to the attribute of the ArcGIS layer using the formula in the Environmental Policy Integrated Climate (EPIC). Using a field calculator, complete the calculation of soil erodibility factor values (K values) for different soil subclasses in the study area and create a K factor map.
2. The LS factor of slope length is generated on the basis of DEM. The slope length is calculated by filling the depression and calculating the flow direction, and the distance of the flow path is estimated.
3. Using the Landset-8 OLI_TIRS image of Zhaoyang in 2019, the NDVI and vegetation coverage were calculated, and the land use type map of Zhaoyang was made by supervised classification. The C value of the study area was calculated according to the relationship between vegetation coverage and the C value, and the C value map of the vegetation cover factor was made.
4. Using ENVI, land use is divided into six types: grassland, farmland, shrub land, water bodies, forests, and artificial land. According to the classification of land use, the soil and water conservation factors are assigned according to the research results of relevant scholars, and then the P value map is calculated.
5. Using the Chinese precipitation data set. csv data and _PRE annual precipitation data, the precipitation distribution map of Zhaoyang is obtained by mask extraction, and the R factor diagram is obtained by inputting the formula of precipitation erosivity factor into the grid calculator.
6. The soil erosion modulus is obtained by multiplying the layers of the above factors and then classified according to "Standards for classification and gradation of soil erosion (SL 190Mir 2007)".

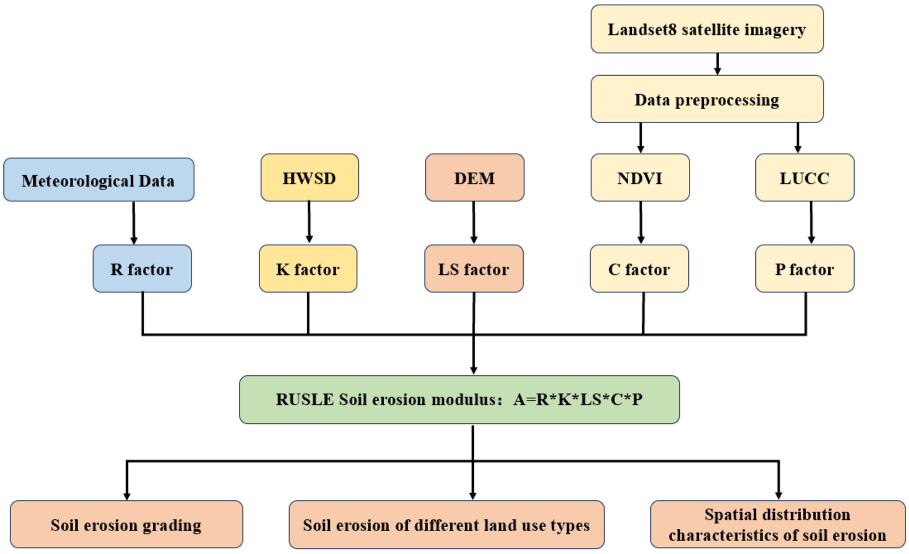

Fig.1 The Scheme of the Study

3.2 RUSLE Model

In this study, the RUSLE based on the USLE was used to calculate the soil erosion status in Zhaoyang. Compared with the USLE and RUSLE models, the structure of the model is simple, the physical meaning of the parameters is clear, the calculation is simple, and it has strong practicability and comprehensiveness. The mathematical expression for RUSLE is as follows:

$$A=R\times LS\times K\times C\times P\ldots\ldots (1)$$

In formula (1), A is the annual average soil loss ($t/(hm^2\cdot a)$); R is the rainfall and runoff erosion factor ($(MJ\cdot mm)/(hm^2\cdot h\cdot a)$); K is the soil erodibility factor ($(t\cdot hm\cdot h)/(MJ\cdot mm\cdot hm)$); LS are the topographic factor, where L is the slope length factor and S is the degree factor; C is the vegetation cover and management factor. P is a factor of soil and water conservation measures, all of which are dimensionless factors.

3.3 Model Parameter Construction

■ LS Factor

Among topographic factors, slope has the greatest impact on soil erosion. The steeper the slope is, the shorter the convergence time, the faster the water flow speed, the greater the runoff energy, and the more severe the erosion on the slope surface. The potential erosion force of the soil is greater. Generally, the erosion amount is directly proportional to the slope. Secondly, the longer the slope length, the larger the surface runoff area and the greater the surface runoff flow, which gradually increases the amount of sediment carried by the water flow and exacerbates soil erosion in the area. The slope length factor is generally generated based on DEM. The calculation of slope length is estimated based on the distance of the water flow path by filling the depression (Figure 3) and calculating the flow direction (Figure 4).

$$L = (\frac{\lambda}{22.13})^{m}$$

$$\lambda = l \times \cos\alpha \qquad (2)$$

In equation (2), L is the slope length factor (dimensionless); λ is the horizontal projection slope length (m); L is the length of water flow along the surface flow direction (Figure 5); α is the slope value of the water flow area (Figure 6); M is a variable slope index; when $\theta < 0.57°$, m = 0.2; when $0.57° \leq \theta < 1.72°$, m = 0.3; and when $1.72° \leq \theta < 2.86°$, m = 0.5, from which the slope length factor L value in the Zhaoyang area can be calculated.

The slope calculation is based on grading, with the McCool DK formula used for slopes below 10° and the Liu et al. formula used for slopes above 10°.

$$S = \begin{cases} 10.18 \times \sin\theta + 0.03 & \theta < 5^{\circ} \\ 16.80 \times \sin\theta - 0.50 & 5^{\circ} < \theta \leq 10^{\circ} \\ 21.91 \times \sin\theta - 0.96 & \theta > 10^{\circ} \end{cases} \qquad (3)$$

In the formula, S is the slope factor (dimensionless); θ is the slope, and the slope factor S is calculated (Figure 7).

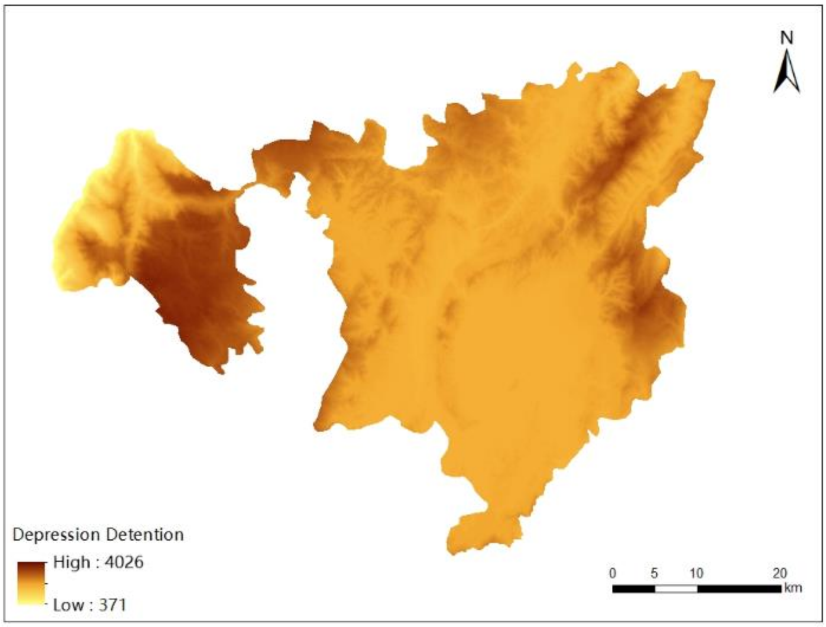

Fig.3 Filling Depression Map

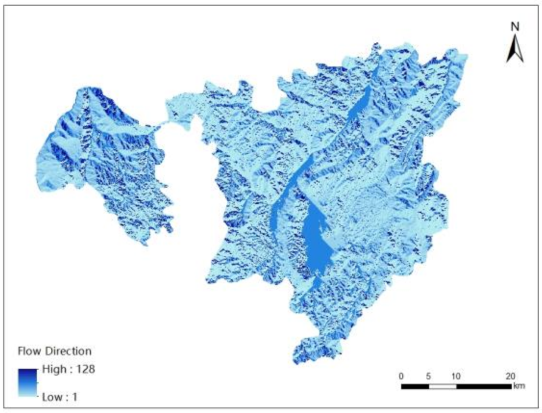

Fig.4 Flow Direction Diagram

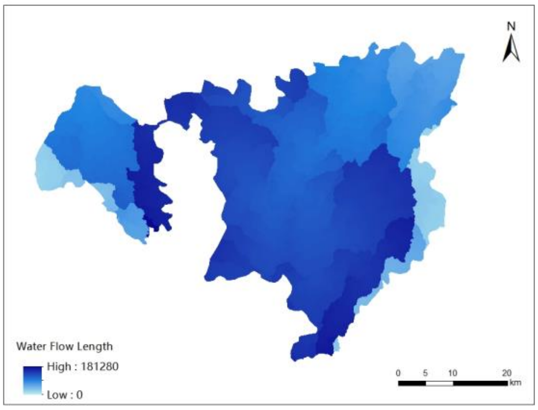

Fig.5 Current Length Map

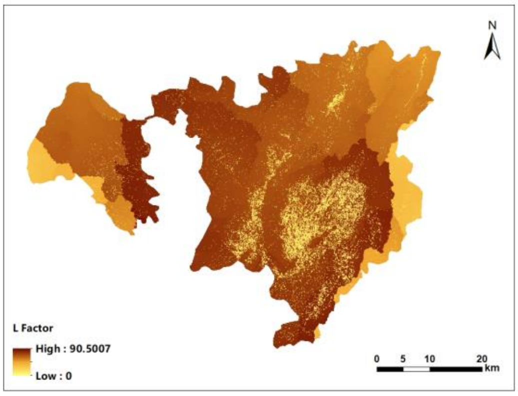

Fig. 6 L-factor

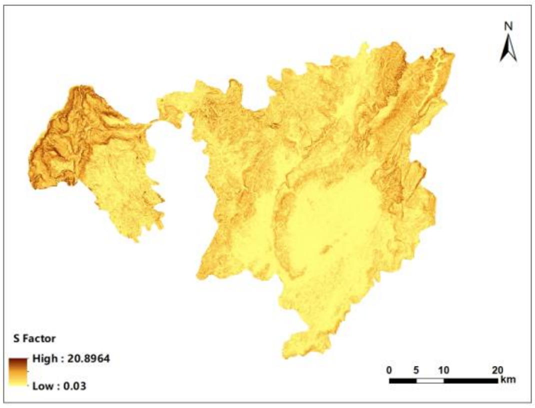

Fig.7 S-factor

■ K Factor

At present, there are four main calculation methods to determine the value of the K factor: the direct determination method, the formula method, the look-up table method, and the Nomo diagram method. In the formula method, the EPIC model method proposed by Williams et al. is the most widely used [15]. This method is mainly calculated by measuring soil mechanical composition, soil organic carbon content, and other soil physical and chemical properties. The data is easy to obtain, and the calculation result is reliable. Therefore, this study intends to use the EPIC model method to calculate the soil erodibility factor K value. The calculation formula is as follows:

$$K = 0.1317\left\{0.2 + 0.3\exp\left[-0.256Sa\left(1-\frac{Si}{100}\right)\right]\right\} \times \left(\frac{Si}{Si+Ci}\right)^{0.3} \times \left(1-\frac{0.25Ca}{Ca+\exp(3.72-2.95Ca)}\right) \times \left(\frac{0.7Sn}{Sn+\exp(-0.51+22.9Sn)}\right) \ldots (4)$$

In formula (4), K is soil erodibility, and even if the resulting unit is an American unit, the result value needs to be multiplied by a conversion factor of 0.1317 to be converted into an international unit. Sa is sand content, Si is silt content, Ci is clay content, and Ca is organic matter content. The above K-value estimation method is only applicable in the United States and not in China. It is necessary to use the correction formula established by Zhang Jili et al. to correct the soil erodibility factor, KEPIC. The calculation formula is as follows: (K is the modified soil erodibility value, and EPICK is the soil erodibility value estimated by the EPIC formula.)

$$K = -0.01383 + 0.051575K_{EPIC} \qquad (5)$$

■ R Factor

Rainfall erosion is one of the key driving factors leading to soil erosion, causing widespread soil erosion worldwide, represented by the capital letter R. The erosive force of rainfall cannot be directly measured, and effective methods need to be used to accurately estimate it. The main methods include simple algorithms and classical algorithms. However, classical algorithms require extremely high temporal resolution for rainfall data, so this study uses a simple algorithm for calculation. As shown in equation (6),

$$R^n = 0.053 \times P_n^{1.655} \qquad (6)$$

In formula (6), R^n is the annual rainfall erosivity factor, P_n is the annual rainfall, and the unit is mm.

■ C Factor

The type of vegetation will affect the spatial distribution pattern of soil erosion, and the increase or decrease in vegetation coverage will affect soil erosion. Therefore, it is essential to study the temporal and spatial distribution characteristics of vegetation coverage to effectively control soil erosion and guide the work of soil and water conservation. When calculating the C value, it is necessary to calculate NDVI (Figure 8) and FVC (Figure 9), mainly as formula (7).

$$FVC = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \qquad (7)$$

In formula (7), FVC is vegetation coverage, NDVI is pixel value, and $NDVI_{max}$ and $NDVI_{min}$ are NDVI values with vegetation cover and NDVI values of bare soil, respectively.

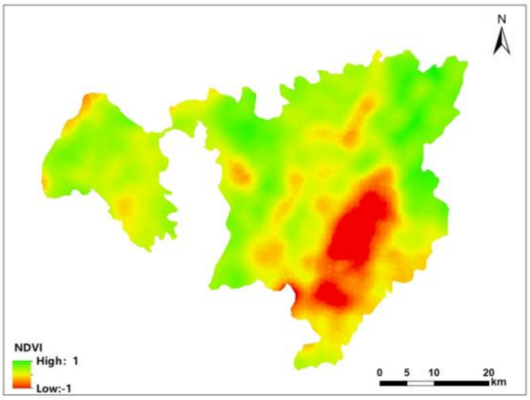

Fig.8 NDVI Value Map

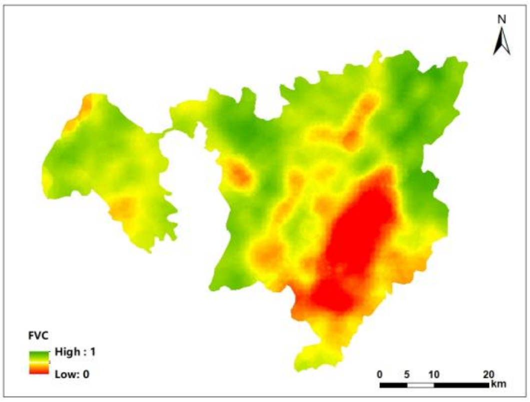

Fig.9 FVC Value Map

■ P Factor

The factor of soil and water conservation measures refers to the ratio of soil loss under certain soil and water conservation measures to the soil loss of sloping agricultural plots without implementing soil and water conservation measures. The ratio P is generally between 0-1, where 0 represents areas with good prevention and control measures and minimal erosion, and 1 represents areas where relevant measures have not been implemented. At present, there is no unified standard for assigning values to soil and water conservation factors in China. After referring to a large amount of literature, this study divides land use into six categories: grassland, farmland, shrubland, water bodies, forests, and artificial land (Figure 10). Based on the classification of land use and referring to the research results of relevant scholars, assign values to soil and water conservation factors, reclassify land use types, assign values of 0.10 to grasslands, forests, and shrublands, 0.35 to cultivated land, 0 to water bodies, and 0 to artificial land (Table 2).

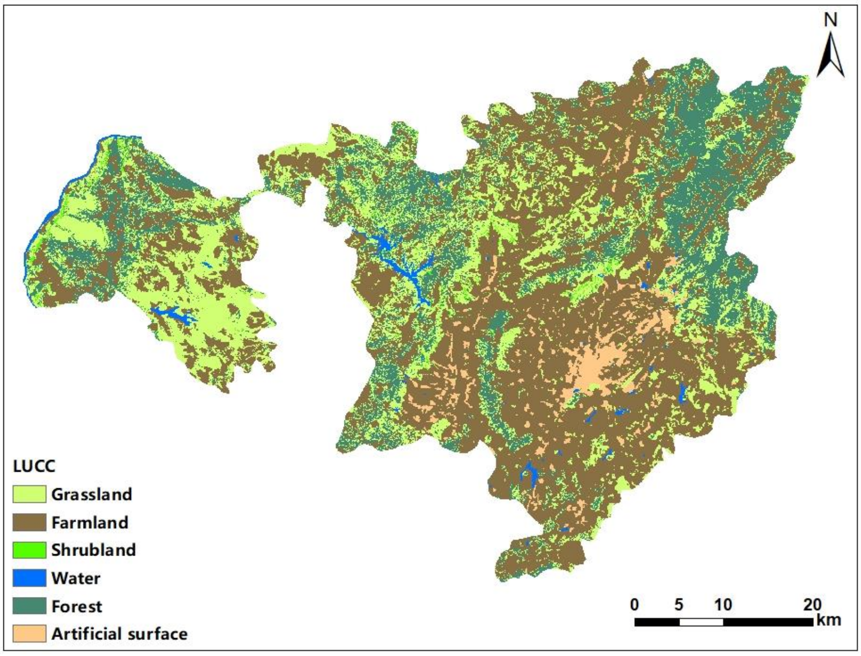

Fig.10 Land Use Map

Table 2 P Value Assignment Table of All Kinds of Land

Land use type	P value	Land use type	P value
Shrub land	0.1	Farmland	0.35
Water bodies	0	Artificial land	0
Grassland	0.1	Forests	0.1

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IV. ANALYSIS AND RESULTS

4.1 The Spatial Distribution of LS Factor

The results of data analysis show that the high value of the LS factor (Figure 11) in Zhaoyang is mainly distributed in the northern region, especially in the northwest region where the Jinsha River is located, reaching the highest value of 1590.06. Combined with the DEM map (Figure 12) and slope map (Figure 13) of Zhaoyang, the topography of the high-value distribution area is larger, while among the LS factors, the slope has the greatest influence on soil erosion, and the steeper the slope is, the shorter the confluence time is. The faster the flow speed is, the greater the runoff energy, and the more severe the erosion on the slope, the greater the potential soil erosivity. In general, the amount of erosion is proportional to the slope. Secondly, the longer the slope length is, the larger the surface confluence area and the larger the surface runoff, which makes the sediment carried by the flow gradually increase. However, the low values are mostly distributed in the urban area of Zhaoyang, where the topography is relatively flat.

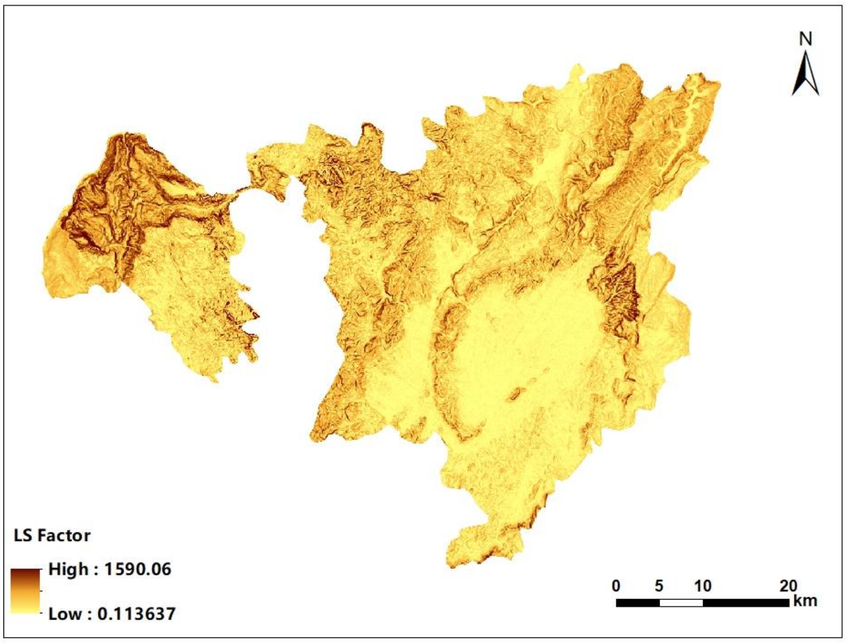

Fig.11 LS factor

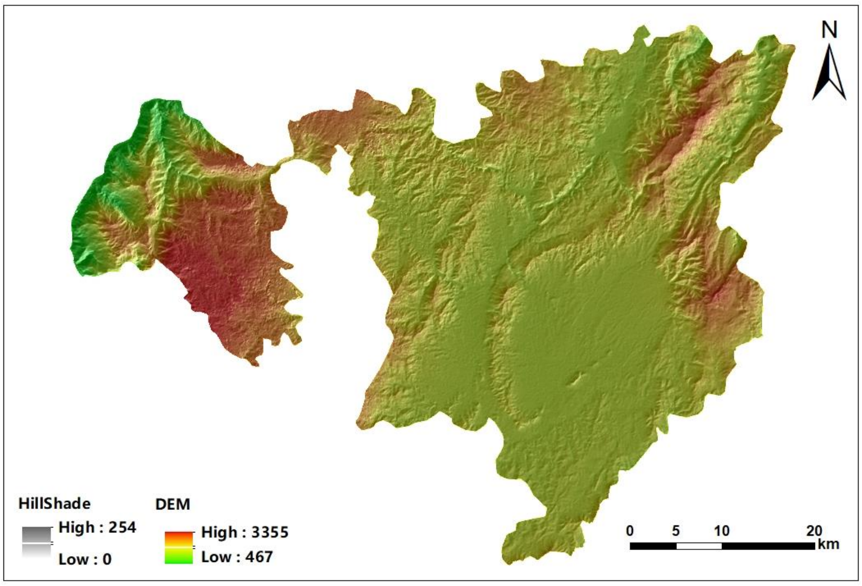

Fig.12 DEM of Zhaoyang District

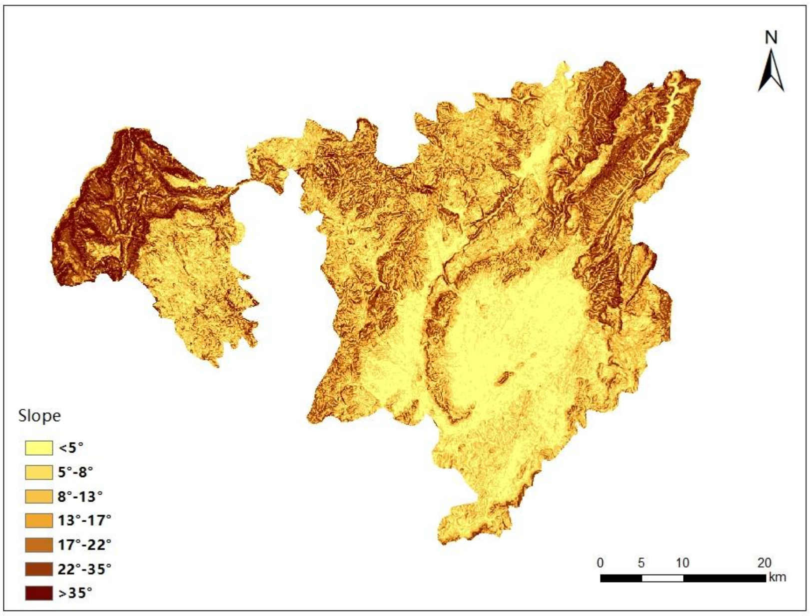

Fig.13 Slope map

4.2 The Spatial Distribution of K Factor

Data analysis shows that the highest soil erodibility K value is distributed in the building area of the urban center of Zhaoyang (Figure 14), and the artificial land is not easy to seepage, which is an important reason for the high soil erodibility factor. The low value of the K factor is mostly distributed in the covered and luxuriant areas, such as the grassland in the west and the forest in the east.

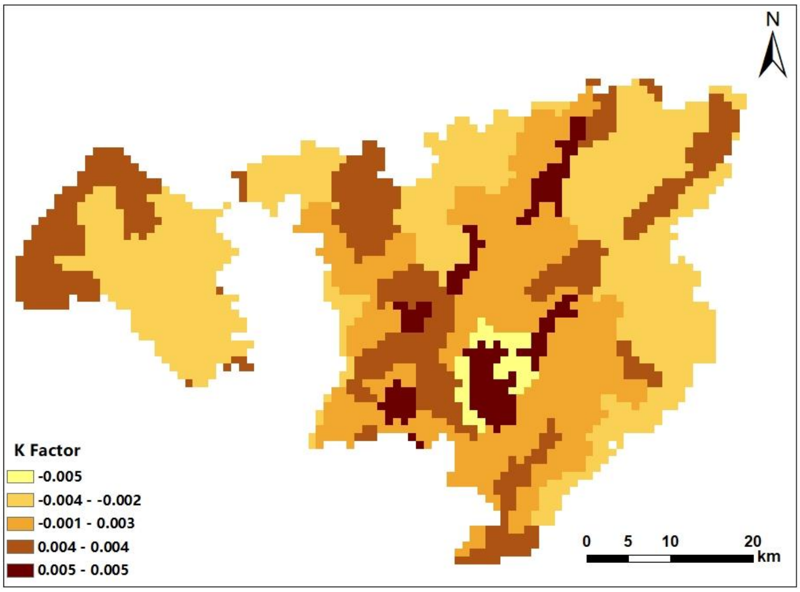

Fig K factor

4.3 The Spatial Distribution of R Factor

From the R factor value distribution map of rainfall erosivity (Figure 15), it can be seen that the rainfall erosivity intensity is basically caused by the precipitation intensity. In 2019, the rainfall erosivity in Zhaoyang changed to 2336.66-7196.72 (MJ*mm)/(hm2*h*a), showing a distribution law decreasing from northwest to southeast as a whole. The minimum value of the R factor in the study area appears in the southeast, and the maximum value appears in the northwest. According to the climatic characteristics of Zhaoyang, because most of the precipitation in the area is a short-term concentrated rainstorm, the scouring force on the soil is enhanced, which increases soil erosion.

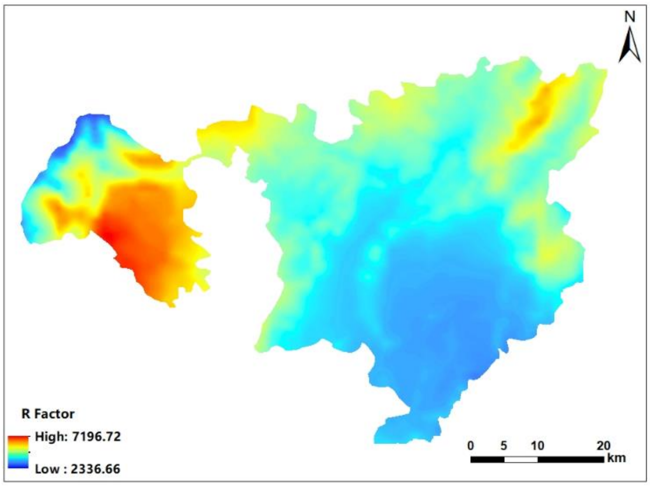

Fig.5 R Factor

4.4 The Spatial Distribution of C Factor

Vegetation is the key factor in controlling the occurrence and development of soil erosion; the type of vegetation will affect the spatial distribution pattern of soil erosion, and the increase or decrease in vegetation coverage will have an impact on soil erosion, as can be seen from the C factor map (Figure 16). The value range is between 0 and 1, and the closer the value is to 1, the higher the vegetation coverage. The high value of vegetation coverage in the study area is mainly distributed in the areas where the land use type is forests and grassland; the low value is distributed in the area where the land use type is farmland; and the lower value is mainly distributed in the area where the land use type is opaque water surface, less vegetation coverage.

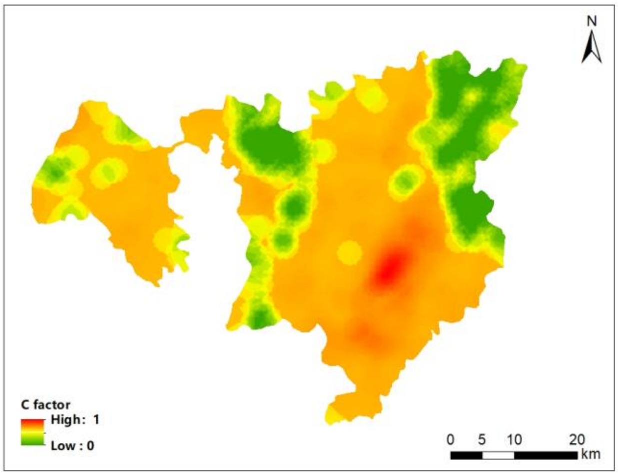

Fig.16 C Factor

4.5 The Spatial Distribution of P Factor

The soil and water conservation measure factor refers to the ratio of soil loss to the soil loss of the farming land along the slope without soil and water conservation measures under certain soil and water conservation measures; the ratio P is between 0 and 1, and the prevention and control measures of generation 0 are very good. That is, the area where erosion basically no longer occurs; 1 represents the area where the relevant measures have not been implemented. According to the research results (Figure 17), the high value of the P factor of soil and water conservation measures is distributed in the southern cultivated area, indicating that the soil and water conservation is poor and the erosion is serious in the Zhaoyang area. The low value of the P factor of soil and water conservation measures is distributed in the artificial land area in the southeast, which makes the surface water unable to seep, and it is also difficult to cause erosion to the surface soil.

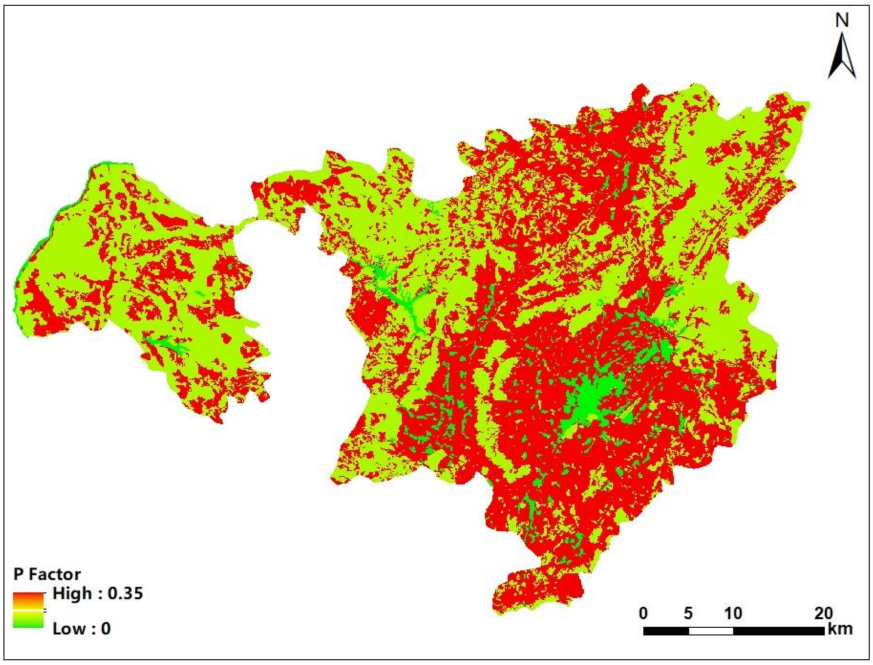

Fig.17 P Factor

4.6 Soil Erosion Characteristics

The soil erosion modulus in Zhaoyang is calculated based on the RULSE model. According to "Standards for classification and gradation of soil erosion (SL 190Mil 2007)," the soil erosion modulus （[t/（hm^2·a）]）in Zhaoyang can be divided into six grades: microscopic erosion, mild erosion, moderate erosion, strong erosion, extremely strong erosion, and severe erosion, and the spatial distribution characteristics of soil erosion are evaluated and analyzed. The results of soil erosion grade classification and spatial analysis are as follows: According to the soil erosion intensity classification map (Figure 18), most of the land in Zhaoyang belongs to microscopic erosion, followed by mild erosion and moderate erosion. The erosion distribution area of the strong grade is small, but it shows the characteristics of concentrated distribution, and the erosion intensity decreases from northwest to southeast, showing certain regularity. Strong erosion is mainly in the northwest of Zhaoyang, where the topography is undulating, indicating that altitude, slope, and other factors have a special impact on soil erosion.

From the soil erosion area of different intensities (Table 3), microscopic erosion accounts for the largest area, which is 1326 km², accounting for 64.4%. With a mild erosion area of 362 km², next only to microscopic erosion, its erosion area accounts for 17.58%. With a moderate erosion area of 247 km², the proportion is 11.99%. There are small differences in the proportion of areas with strong erosion, extremely strong erosion, and severe erosion, with erosion areas accounting for 3.74%, 1.55%, and 0.74%, respectively. The above analysis indicates that soil erosion in Zhaoyang is characterized by slight and mild erosion, but the proportion of extremely strong and severe erosion is relatively large. Therefore, in the construction of the regional soil and water conservation ecological environment, attention should be paid to the management of soil and water loss with extremely strong and severe erosion levels.

The erosion environment of different land use types and the intensity affected by human activities are different, which leads to great differences in the soil erosion characteristics of different land uses. Combined with the land use map (Figure 10) and the erosion intensity map (Figure 18) in Zhaoyang, we can see that there are great differences in erosion intensity among different land use types. From the point of view of erosion intensity, the erosion intensity of farmland is large, and the erosion intensity of grassland is in the grade of moderate erosion; the erosion intensity of forests is small, which is in the grade of slight erosion. Which is indicates that the effect of soil and water conservation in forests is good; there is almost no erosion in construction land, water areas, and other land use types, or the amount of erosion is very small, which is in the range of slight erosion as a whole. In terms of the proportion of erosion of different land use types, shrub land, forests, and grassland are the main sources of regional erosion, while other land use types account for a small proportion of erosion.

Table 3 Area of Soil Erosion at All Levels

Erosion level	Erosion area（km^2）	Percentage（%）
Microscopic erosion	1326	64.4%
Mild erosion	362	17.58%
Moderate erosion	247	11.99%
Strong erosion	77	3.74%
Extremely strong erosion	32	1.55%
Severe erosion	15	0.74%

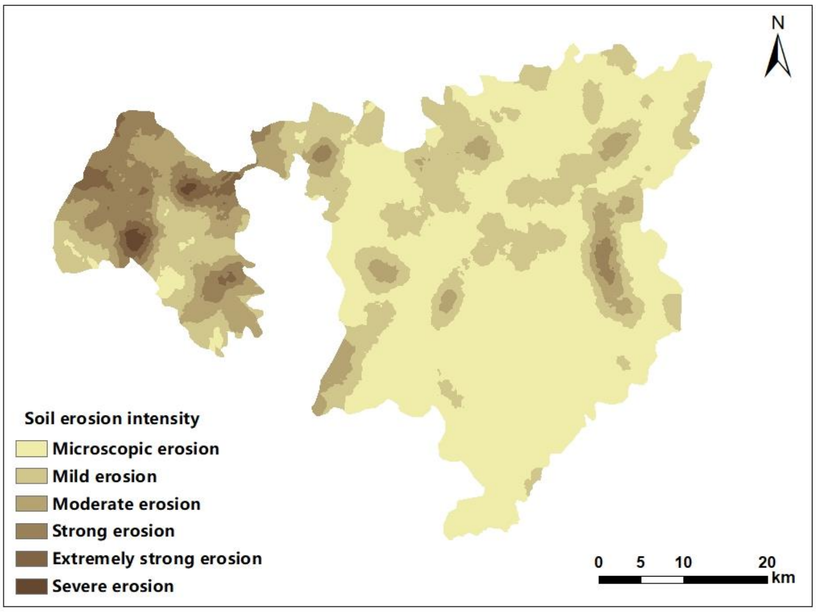

Fig.18 Soil Erosion Intensity Map

V. CONCLUSION

This study mainly uses the combination of ArcGIS and ENVI, analyzes the spatial distribution characteristics of soil erosion in Zhaoyang based on the RUSLE model, and studies the effects of soil erosion classification and different land use types on soil erosion. The results are as follows:

The intensity of soil erosion in Zhaoyang increases gradually from southeast to northwest, and most of the land is subject to slight erosion. The second is mild erosion and moderate erosion, and the strongly eroded soil is concentrated in the northwest, which is greatly affected by altitude and slope factors.

In Zhaoyang, the proportion of soil with slight erosion is 64.4%, the proportion of light erosion area is 17.58%, the proportion of moderate erosion area is 11.99%, and the proportion of strong erosion, extremely strong erosion, and severe erosion is 3.74%, 1.55%, and 0.74%, respectively.

From the perspective of different land uses, the amount of soil erosion in land use types such as construction land and water areas is very small, and it is in the range of slight erosion as a whole. Shrub land, forestland, and grassland are the main sources of regional erosion. Farmland soil and water conservation measures are poor; their P value is larger, so the intensity of soil erosion is high.

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